

Computer Auditing of Surgical Operative Reports Written in English

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ABSTRACT

We developed a script-based scheme for automated auditing of natural language surgical operative reports. Suitable operations (appendectomy and breast biopsy) were selected, then audit criteria and operation scripts conforming with our audit criteria were developed. Our LISP parser was context and expectation sensitive. Parsed sentences were represented by semigraph structures and placed in a textual database to improve efficiency. Sentence ambiguities were resolved by matching the narrative textual database to the script textual database and employing the Uniform Medical Language System (UMLS) Knowledge Sources. All audit criteria questions were successfully answered for typical operative reports by matching parsed audit questions to the textual database.

INTRODUCTION

Natural language is the language usually used by humans to communicate with other humans, and for expressing ideas and knowledge. There are many possible automated natural language processing applications in medicine, but they are complex and there are few practical implementations. Utilization of computers to process medical information inevitably requires natural language processing since most medical knowledge is stored and transferred using natural language.

The inpatient medical record contains the reasons for hospitalization, diagnostic test results, assessment of medical problems, treatment results, patient condition at the time of hospital discharge, and patient disposition. Medical records are an important repository of medical information about individual patients and medicine in general. These records are the basis for further treatment and financial reimbursement, and they are a source of data which can facilitate new medical knowledge development. Most medical record data are stored with natural language.

Modern medical care financing involves diagnosis related groups (DRGs), which are about 500 sets into

which all medical problems are classified, and by which government, and some insurance company, medical care financial reimbursement is based. Since the coding (classification) of patient medical problems is not unique, identification and optimum coding of patient medical problems can make a significant reimbursement difference. Specially trained clerks are often employed to review medical records to determine the DRG coding that maximizes reimbursement. Automation of DRG coding optimization would have significant practical value, but it is not available yet [1].

Auditing medical records for adherence to established guidelines and for unusual occurrences is an important strategy for maintaining quality medical care and continuous quality improvement of medical care [2]. Detailed auditing criteria have been established for the indications and expected results associated with many surgical procedures. Auditing medical records using such criteria is tedious, time consuming, and error prone. Automation of this auditing process would save time, improve efficiency, and improve the quality of care by enabling auditing of more, or all, medical records [3].

The operative report is a natural language narrative required in the medical record of a patient on whom a surgical procedure has been performed [4]. The operative report provides a detailed description of what occurred during a surgical procedure.

Informative operative reports should be concise and complete. The development of operative report auditing criteria is reasonable [5]. Such auditing can be used for DRG coding, quality assurance, and training physicians to create proper operative reports. A system which extracts knowledge from natural language operative reports and then applies audit criteria would have practical value, and would be a small step toward automated processing of the entire natural language medical record. The concept of automated natural language operative report processing is not new [6,7].

METHODS

Operative report requirements are specified by the Joint Commission for Accreditation of Hospital Organizations (JCAHO). Operative reports should include a description of findings, technical proce-

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dures, specimens removed, postoperative diagnosis, and names of the primary surgeon and assistants [8].

We discussed operative report auditing criteria with general surgeons and reviewed a standard textbook [9]. Reasonable, important, and practical auditing questions one could ask about, for example, an appendectomy operative report include:

- o What were the anesthesia and incision types?
- o What were abdominal examination results?
- o What was the appendix abnormality?
- o Was there peritonitis or abscess?
- o Were appropriate cultures obtained?
- o Was there appendix stump inversion?
- o Was cautery or drains used?
- o Was there irrigation or skin closure?

We developed similar breast biopsy operative report auditing questions.

Operative reports usually contain formatted information that is intended to meet JCAHO requirements. This structure simplifies automated auditing. The narrative description of an operation is often in a operative report section entitled DESCRIPTION OF OPERATION, e.g. see Figure 1.

A script is a data structure describing an expected event sequence in a particular situation [10]. Routine surgical procedures involve a limited domain, and are amenable to description by a script-based knowledge structure. Operation script development was an essential part of our automated auditing process. Operative reports for emergency or unplanned operations are unsuitable for script-based automated processing because of unexpected outcomes and findings. Similarly, scripts for complex operations

The patient was taken to the operating room, and placed in the supine position on the operating table. The abdomen was prepped and draped in the usual fashion. A transverse Rocky-Davis incision was made in the right lower quadrant of the abdomen. It extended through the subcutaneous tissues, and the peritoneal cavity was entered with a muscle splitting incision. No gross pus was seen in the abdomen. The cecum was identified and the appendix was palpated and was involved in a phlegmon in the right flank. The appendix was retrocecal. It was dissected from the surrounding inflammatory tissue, and the vessels in the mesoappendix were ligated. It was gangrenous in its distal half. The base of the appendix was normal. The base of the appendix was ligated doubly with silk and the appendix was removed. The wound was irrigated with antibiotic containing solution. The deep fascia and peritoneum were closed with a running stitch of 2-0 Vicryl. The external oblique was closed with a running stitch of 2-0 Vicryl. The skin was left open and packed with betadine soaked fine mesh gauze with the intent of performing delayed primary closure in approximately four days. The patient was extubated and taken to the recovery room in good condition. Estimated blood loss was fifty ml.

FIGURE 1. Appendectomy report narrative.

are difficult to develop because as operation complexity increases, outcome variability and possible complications increase.

It is preferable to choose common and routine operations for automated processing technique development. This implies four operations: inguinal herniorrhaphy, breast biopsy, cholecystectomy, and appendectomy. Herniorrhaphy has significant surgical technique variability. Cholecystectomy can have significant variability in operative findings. Breast biopsy is simple and suitable for script-based automated auditing. Appendectomy has some outcome variability, but is a good candidate for automated auditing. After considering the typical appendectomy event sequence, we developed a script (Figure 2). A breast biopsy script was also developed.

SCRIPT: Appendectomy
PROPS: Hospital, laboratory, recovery room
 Operating room, table, supplies
 Anesthesia supplies, equipment
ROLES: Patient, surgeon, assistant, anesthetist
 Surgical nurse, instrument nurse
ENTRY CONDITIONS: Suspected acute appendicitis
 Stable vital signs
 Medical problems controlled
RESULTS: Appendix removed from patient
 Specimens and cultures to laboratory
 Abscess drained, drains placed
 Appendix stump inversion
 Cautery used
 Skin closed
 Abdominal exploration
 Sponge count verified
 Return to recovery room
SCENE 1: Entry
 Bring patient to operating room
 Induce anesthesia
 Prep and drape abdomen
 Make abdominal incision
SCENE 2: Exploration
 If appendix normal then
 Examine abdomen
 Else
 Classify abnormality
 Is abscess present?
 Is peritonitis present?
SCENE 3: Appendectomy
 Remove appendix
 Send specimens to laboratory
 Is appendix stump inverted?
 Is cautery used?
SCENE 4: Exit
 Is abdominal abscess drained?
 Is abdomen irrigated?
 Are drains placed?
 Is skin closed?
 Verify sponge count
 Bring patient to recovery room

FIGURE 2. Appendectomy script.

Operative narrative analysis was the focus of our natural language processing. We assumed all operative reports were properly formatted and grammatically correct, and that all words were correctly spelled. A reliable script is useful since it can provide clues for resolving some operative report uncertainties and ambiguities, e.g. pronoun and implied subject references.

The UMLS was recently made available by the National Library of Medicine [11]. UMLS development has been an extraordinary effort [12] that provides a valuable adjunct for medical language processing by computer. UMLS Knowledge Sources unify medical terminology systems that have developed over the last 50 years. We developed personal computer based programs to extract useful information from the UMLS Knowledge Sources, and then implemented LISP functions enabling retrieval of syntactic and semantic types, definitions, synonyms, lexical variants, and semantic network information for UMLS terms. Extensive UMLS knowledge can be put to good use in medical language processing applications, e.g. it is useful to have readily available synonyms for operative narrative terms when attempting to match operative narrative sentences with a script.

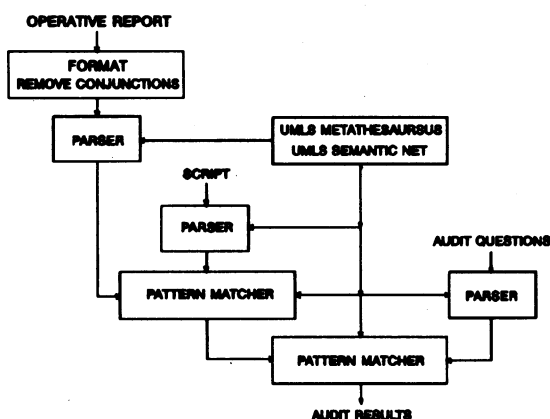


FIGURE 3. Processing stages.

Our operative report processing strategy is staged (Figure 3). Formatting extracts important information from the free text operative report and puts it in a form easily manipulated by LISP programs. Conjunctions increase natural language parsing complexity. At least one-half of operative report sentences contain conjunctions. It is rare for alternative possibilities (e.g. expressed with the conjunction *or*) to be described in operative reports since they are descriptions of past events. However, conjunctions (primarily *and*) are often used in the dictated medical language of operative reports. Our second narrative

processing step is transformation of narrative sentences into simpler sentences with equivalent meaning but no conjunctions.

We used semigraphs to represent sentences [13]. Sentence subject and object are semigraph nodes, and the verb is a directed arc connecting subject and object nodes. Subject, object, and sentence attributes (adjuncts, adverbials, prepositional phrases) are non-directed arcs connected to the appropriate node (Figure 4). Complex sentences are easily represented by this structure. This semigraph model is useful for parsing and assessing sentence coherence, i.e. coherence assessment is reduced to finding semigraph element similarities.

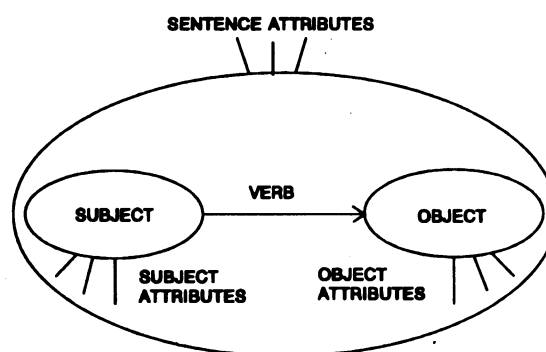


FIGURE 4. Sentence semigraph structure.

We used a context and expectation sensitive parser written by ZM Wojcik in which sentence element is determined by context. Expectations and context are assessed using the sentence semigraph structure. The parser must be provided the syntactic type (noun, verb, etc.) of each sentence word. This is done by a dictionary program, but if a word is not in the dictionary then the UMLS database is searched for syntactic word type before prompting the user for the word type.

The parser changes sentences to structured lists:

((subject)(verb)(object))(adverbials)(attributes)).

All sentence adverbials are placed in the *(adverbials)* slot. Sentence attributes such as voice, tense, and type are placed in the *(attributes)* slot. This list, equivalent to the sentence semigraph representation, provides fast and easy access to important sentence components while retaining important sentence information. Using this representation the sentence *the nurse brings the patient to the operating room* is parsed:

((nurse the)(bring)(patient the))

((to (room operating)))(AV PS DECL)).

AV means active voice, PS means present simple tense, and DECL means declarative sentence.

The operative narrative is transformed to an

indexed sentence database [14] or textual database [15], i.e. a list of all parsed sentences with sentence index frame information. This format facilitates script matching and narrative coherence relation determination since separate indexed lists of sentence elements can be constructed. Such a database provides a processing speed advantage since narrative words do not have to be extracted from complex parse tree list structures such as those generated by an ATN parser. This processing strategy is also easily implementable on parallel processors.

Script information can resolve some operative report narrative implied subject and pronoun reference ambiguities (ellipsis). This is essential in the operative report domain where sentence voice is frequently passive. If voice is passive, then there is often an implied subject. Consider the passive sentence *the patient was taken to the operating room*. The object *patient* receives the action of the verb *taken*. This sentence could be transformed to the active sentence *someone took the patient to the operating room* where the subject is *someone*. The identity of implied subjects in these two sentences must be known if script-based pattern matching is to succeed in extracting information from the operative report narrative. The parser transforms *the patient was taken to the operating room* to:

(((?subject)(take)(patient))
((to (room operating)))(PV PP DECL)).

Here *?subject* designates a subject of unknown identity. Similarly, pronoun identity is unknown. Consider the passive sentence *it was removed*. Since there is both an implied subject and a pronoun object, the sentence is parsed:

(((?subject)(remove)(?object))(nil)
(PV PP DECL)).

Operative report narrative sentences can be antecedents that imply consequents within a script framework. The strategy is to compare the operative report narrative to a script textual database that has been extended with *IF-THEN* rules to create a kind of expert system.

An exact match exists if script and narrative sentences have the same subject, verb, and object. Since variables *?subject* and *?object* are unbound, they match anything. The first step is to ascertain exact matches between script and narrative sentences, i.e. each parsed operative report narrative sentence is evaluated to see if it exactly matches any script textual database sentence to resolve implied subject and pronoun references and to add new knowledge from any script *IF-THEN* rule consequents. If an operative narrative sentence matches the antecedent of

a script *IF-THEN* rule, then the consequents of the *IF-THEN* rule are assumed to be true even though they are not explicitly stated in the operative report, and the consequents are added to the operative narrative textual database.

Next UMLS semantic network information is employed to match as many unmatched sentences as possible to script sentences in order to resolve more unknown references and add additional knowledge. As each sentence is processed, semantic net types are substituted for each verb, object, and subject as appropriate to obtain a match with a script sentence. All semantic network type substitution combinations are attempted.

Operative note auditing is performed by parsing the audit questions and comparing audit question subject, verb, and object to textual database sentences. If there is a match, then questions that can be answered yes or no (e.g. *did the surgeon see pus?*) can be immediately answered, or information can be extracted for the answer (e.g. *surgeon made a transverse Rocky-Davis incision in the right lower quadrant of the abdomen*).

RESULTS

Automated auditing results for two appendectomy and two breast biopsy operative reports were accurate, i.e. the answers to all audit questions were correct. The script matching process was effective in resolving ambiguities in the original operative narratives. One operative report narrative (Figure 1) had 27 sentences after conjunction removal, and the voice was passive in 23 of these sentences. Script matching correctly identified implied subjects in all but three passive voice sentences. There were three pronoun references, and script matching revealed the correct identity of them all. Two new sentences could be added to the operative narrative textual database because they were consequents of a matching script *IF-THEN* rule. UMLS Knowledge Sources provided syntactic type information that could be used for parsing for about 20 percent of operative narrative words. The results were similar for the other operative reports that were processed.

DISCUSSION

This study addresses a practical problem. Auditing operative reports to enhance medical care quality and teach the practice of medicine is a important task. Automation of this task is reasonable. The development of scripts for operative report auditing is essential for the methodology of this study.

A unique opportunity for improved knowledge

representation in medicine has recently become available as the UMLS. Practical methods for dealing with the huge amount of UMLS information (metathesaurus and semantic nets) were developed for the study. UMLS data can be put to good use on small systems.

Since operative reports entail a specialized use of conjunctions, a method was developed to simplify the parsing complexity of dealing with sentences containing these conjunctions.

Representation of parsed sentences with a semi-graph data structure speeds processing since complex parse tree traversal is not required. The representation of parsed narrative sentences with an index frame system (textual database) facilitated pattern matching of operative report narrative with operation script.

Scripts were carefully developed for appendectomy and breast biopsy. These scripts were important for successful language understanding.

The script, textual databases (script and operative report narrative), synonyms, and UMLS semantic network were used to resolve the identity of about 80 percent of the typically numerous operative narrative implied subjects, and all pronoun references. The resolution of such ambiguities is essential for successful development of a data retrieval system for natural language operative narratives.

Matching was done in stages from the most specific to the most general. Operative report narrative sentences were first checked for an exact match to the operation script. If this failed, then synonyms were substituted for operative report narrative words in an effort to find an exact match with the operation script. If this failed, then the last stage was to use the UMLS semantic network to substitute more general semantic network terms for operative report narrative words in an effort to appropriately match the operation script.

The final step of operative report auditing processing was matching parsed audit questions against the operative report textual database modified through operation script matching. The final report was generated by this step.

This study could be the basis of much future work. The LISP program needs to be tested with a variety of operative reports. When an appropriate number of appendectomy operative reports have been processed, then it is reasonable to modify the system to process other kinds of operative reports. The ultimate goal will be the automated processing and auditing of the entire natural language medical record, which will soon all be available in electronic form.

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